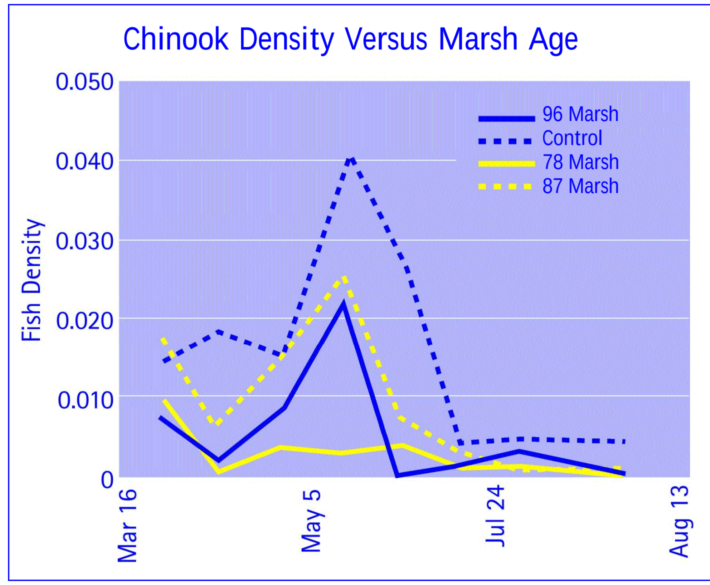
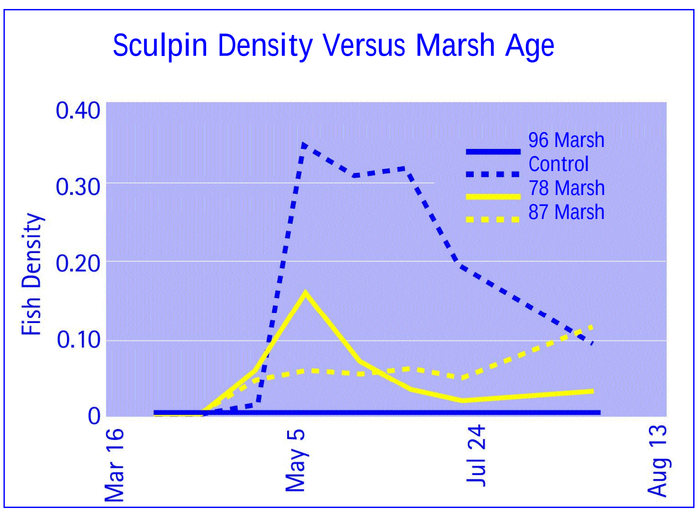
TIDAL WETLAND RESTORATION
PROMISE & UNCERTAINTY

Charles A. Simenstad, University of Washington

Within a decade, tidal marsh restoration in the Pacific Northwest has transcended rapidly from relatively improvised compensatory mitigation for wetland loss to ecosystem-scale initiatives for public-funded, non-compensatory recovery of important fish and wildlife habitat and other ecological, hydrological and cultural functions. This suggests that our technical ability to restore tidal marshes, and to accurately assess their functional response, has become increasingly more effective. However, as many critiques have noted, our efforts often have led to only partial success, if not abject failure — a present conundrum of tidal wetland restoration, which, despite its obvious promise, has yet to appreciably lower the uncertainty of the outcome.





Densities of juvenile chinook (top right graph; Oncorhynchus tshawytscha*) and Pacific staghorn sculpin (bottom;* Leptocottus armatus*) in Salmon River estuary marshes of differing restoration ages (dikes breached in 1978, 1987 and 1996) and undiked reference (control) marsh in 1998. Unpublished data from D. Bottom (NMFS-Newport) and T. Cornwell (ODFW-Corvallis).*

There are some clearly promising things about restoration:

- **Restoration happens**: Natural marsh restoration is readily apparent by the mature state of many marshes in the Pacific Northwest that have been restored without human intervention.
- **Marsh-building processes persist**: To a large degree, underlying processes are still operative if often moderated — salinity regimes remain, suspended material still provides minerals and organic matter for accretion, and plant and animal recruitment is pervasive.
- **Many functions respond rapidly**: While some functions require lengthy processes, the return of the tide often promotes rapid functionality, as in an increased tidal prism contributing to floodwater storage and to habitat and food web support for important resources such as salmon.

NEW SCIENCE

Comparing Restored Tidal Marshes of Varying Ages

An investigation comparing three tidal wetland restoration sites with a natural marsh indicates that biological communities in restored wetlands have different rates of establishment and that similarity to natural marshes may take a considerable period of time to evolve. The study investigated changes in soil characteristics and biological community heterogeneity at four wetland sites: a 3 month-old Caltrans mitigation site in the Albany mudflat; a 7-year-old channel at the Corde Madera Ecological Reserve; a 13-year-old mitigation site (Lincoln Properties) in Richardson Bay; and the 3-4,000 year-old Hoffman Marsh. Wetland functions and attributes evaluated included soil bulk density, organic content and particle size distribution; vegetative community heterogeneity and plant biomass; benthic community heterogeneity; and fish utilization of tidal channels. Samples were taken in October 1998 within the tidal channel, along the channel edge, and in the high marsh; aerial photographs helped with biomass evaluation and blocking nets and beach seine with fish samples. Results indicated that wetland functions within restored marshes exhibited temporal and spatial variation with increasing age. Some functions (such as bulk density and vegetative biomass) approached that of natural marshes within a relatively short period of time. Other functions (such as organic matter development and benthic community structure) increased steadily over the 13 years observed in this study, but were not similar to the natural marsh. Some functions (such as fish use) do not appear to be related to marsh age but to geomorphic features and proximity to other habitats (Buisson et al, SOE Poster, 1999).

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REHAB ADVICE

- Avoid functional forcing. Designing restoration for one or two functions (e.g. designing habitats rather than ecosystems) is risky. Despite the pressing need to address threatened and endangered species, failing fisheries, and other arguments for tidal marsh restoration,unifunctional restoration restricts or prohibits the broader benefits of marshes.
- Give proper consideration to local and regional constraints. Interactions between structure (and function) and process are often overlooked, as is the fact that many critical processes have been irrevocably altered. Many projects pay insufficient attention to constrictions in the natural landscape, contaminant source control and non-indigenous species, which are prepared to pounce on new disturbances.
- Resist demands for instant gratification. We expect marshes to mature in far less time than natural processes allow. Understanding rate-limiting processes can prescribe approaches to accelerate development, but such intervention can be counterproductive because progression is often an essential precursor to functional equivalency.
- Avoid maladaptive monitoring. Monitoring response without evaluating underlying processes neither amplifies knowledge, nor leads to corrective actions (Simenstad, SOE, 1999).

Our challenge is to have appropriate science and engineering to evaluate trade-offs, and to know when, how, how long, and how much we must invest in intervention and control. Do we have the patience, the will, and the knowledge to incorporate science, rather than gardening, into tidal marsh restoration? What is the risk, particularly for recovering tidal marsh-dependent species like certain Pacific salmon stocks, of continuing to pursue our present ad hoc approach?

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PROJECT IN ACTION

Geomorphic Processes in the Restored Petaluma River Marsh

Monitoring of the 45-acre Petaluma River Marsh site — restored to tidal action in 1994 — indicates a fairly rapid pace of evolution, underlining the importance of site location and associated geomorphic processes in selecting and designing wetland restoration projects. In the four and a half years since the Petaluma Marsh levee was breached, nearly two meters (six feet) of sediment have accumulated on the subsided site. In addition, a tidal channel network has formed, vegetation now covers approximately 15% of the site, and at least four threatened or endangered wildlife species already use the marsh. Long-term sedimentation rates at the site are high, averaging half a meter per year (1.5 feet) since return to tidal action, with short-term rates over the 1997-1998 El Nino winter reaching nearly one meter per year (3 feet). These sedimentation rates reflect the estuarine position of the project site just upstream of the confluence of the Petaluma River and San Pablo Bay, the site's direct open tidal connection to the Petaluma River, and its shelter from open winds of San Pablo Bay — results suggesting the importance of considering site location and sediment sources, as well as the nature of the tidal connection between these sources when undertaking sediment-dependent restoration projects. The tidal channel network also plays an important role in formation of the marsh. Initial conditions included small pilot channels to guide where larger channels would form and a series of small parallel berms between which a high density of smaller tidal channels have now formed. The current channel network reflects initial conditions in several regards, suggesting design approaches to promote project goals (Siegel, SOE Poster, 1999).

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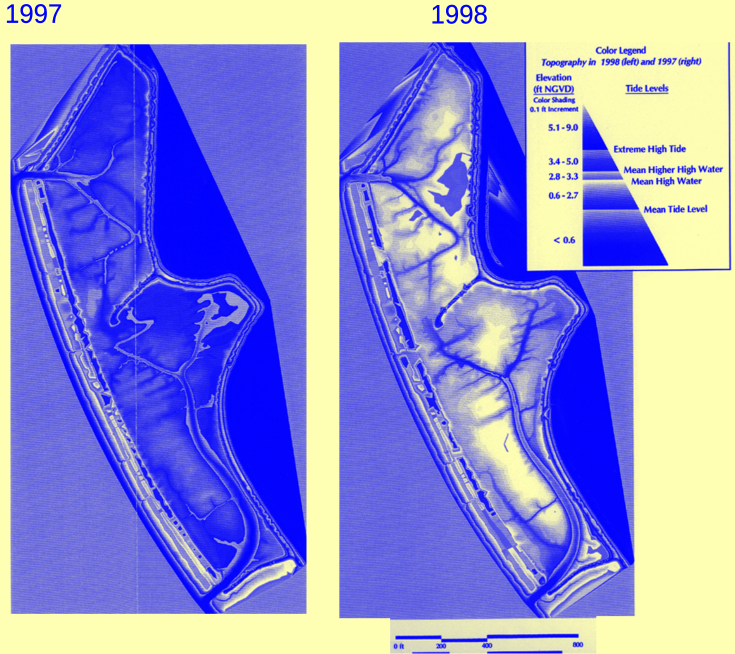
Sediment Accumulation
(Digital Elevation Model Photograph)

1997 1998



BAYLANDS ECOSYSTEM HABITAT GOALS

Mike Monroe
U.S. Environmental Protection Agency

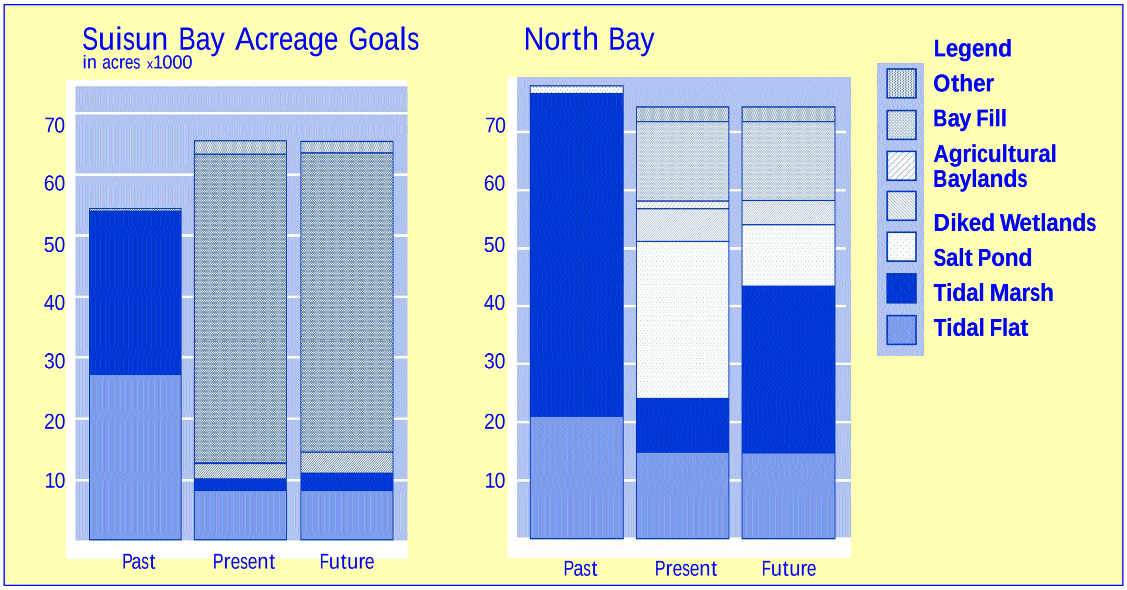
What kinds, amounts, and distribution of wetlands and related habitats are needed to sustain diverse and healthy communities of fish and wildlife resources in the San Francisco Bay Area? The answer to that question was developed after three years of work by more than 100 scientists, resource managers, and other participants in the San Francisco Bay Area Wetlands Ecosystem Goals Project (Goals Project),and released in a 1999 report at the State of the Estuary Conference.

The geographic scope of the Goals Project includes baylands — the lands within the historical and modern boundaries of the tides — in Suisun Bay, San Pablo Bay, and San Francisco Bay. To develop the Goals, participants selected key species and key habitats, assembled and evaluated information,prepared recommendations, and integrated recommendations into goals. In selecting key species, technical focus teams screened nearly 400 species of fish and wildlife and evaluated plant communities from the Bay to the adjacent uplands. The focus teams ultimately selected 120 species of invertebrates, fish,amphibians, reptiles, mammals, and birds to represent the complexity of the baylands ecosystem. In developing the list of key habitats, participants reviewed habitat lists created for previous wetland planning efforts. Ultimately, they designated some two dozen key habitats of the baylands ecosystem. After selecting key species and habitats, participants assembled qualitative and quantitative data on them,prepared initial habitat recommendations, and solicited public comment before releasing final Goals.

The Goals recommendations are founded on one important premise: no additional loss of wetlands within the baylands ecosystem. Furthermore, as filled or developed areas within the baylands become available, their potential for restoration to fish and wildlife habitat should be fully considered. In many areas, achieving the Goals will depend on the willingness of landowners to aid management and restoration efforts.

The specific recommendations of the Goals — which to suggest protection, restoration or enhancement of large areas of baylands habitat throughout the region — are summarized in the *Rehab Advice* section below, and in the charts.

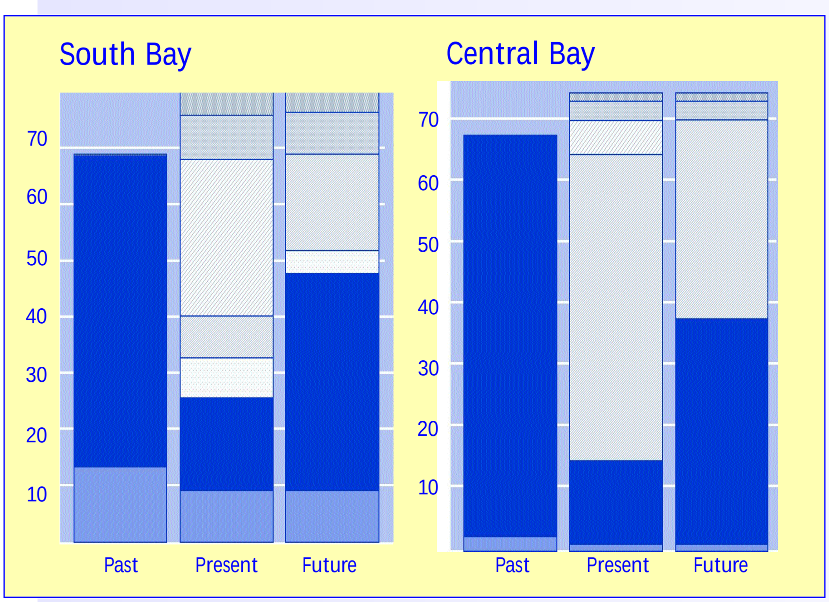
Achieving the Goals region-wide would have major environmental benefits — among them, the recovery of the baylands' many threatened and endangered species. Restoring large areas of tidal marsh would enable populations of salt marsh harvest mouse and California clapper rail to rebound, eliminating the need for their current special protection;improve habitat conditions for the endangered Chinook salmon and the threatened Delta smelt;improve the Bay's natural filtering system and enhance water quality; increase primary productivity of the aquatic ecosystem; and reduce the need for flood control and channel dredging. Likewise enhancing diked wetlands would increase the regional and subregional support of migratory birds. Restoring vernal pools and other seasonal wetlands would reverse declines of unique plant and animal communities. Restoring riparian corridors would benefit many species of amphibians, mammals, and birds.



REHAB ADVICE

REGIONAL LEVEL

- Provide many large patches of tidal marsh connected by corridors to enable the movement of small mammals and marsh-dependent birds; several large complexes of salt ponds managed for shorebirds and waterfowl; extensive areas of managed seasonal ponds;large expanses of managed marsh; continuous corridors of riparian vegetation along the Bay's tributary streams; restored beaches, natural salt ponds, and other unique habitats;intact patches of adjacent habitats, including grasslands, seasonal wetlands, and forests.
- Provide the approximate regional and subregional acreages for the key bayland habitats shown in the bar charts on these pages — keeping in mind that recommended changes should occur gradually over several decades.
- Offset losses of habitats converted to tidal marsh. To offset the conversion of salt pond habitat, the remaining salt ponds should be managed to maximize wildlife habitat functions, particularly for shorebirds, waterfowl,and other water birds. There should be salt pond complexes in North Bay and in South Bay adjacent to important shorebird foraging areas. Each complex should be managed to maintain a range of salinities and water depths that favor the desired bird species. To offset the conversion of agricultural bayland habitat, the remaining agricultural areas should be managed as seasonal pond habitat to improve habitat functions for shorebirds, waterfowl, and other water birds. To offset the conversion of managed marsh habitat, the remaining managed marshes should be managed to increase their waterfowl habitat functions.



- Address technical and policy issues arising from Goals implementation,including: phasing of projects so that the habitat functions of diked baylands — especially seasonal wetlands, salt ponds, and managed marsh — are provided when tidal marsh is restored;determining how and when to use dredged material for tidal marsh restoration; balancing the need for public access with the needs of bayland wildlife; controlling non-native invasive plants and introduced animal species; and ensuring adequate funding to acquire, restore, and manage bayland habitats in the long term.
- Establish a regional science program to support the management and restoration of the baylands ecosystem.
- Develop processes for landowners, agencies and the public to work together to achieve the Goals.

LOCAL LEVEL

Suisun

- Restore tidal marsh on the northern and southern sides of Suisun Bay, Grizzly Bay, and Honker Bay, and restore and enhance managed marsh, riparian forest, grassland, and other habitats.
- In Suisun Marsh, restore tidal marsh in a continuous band from the confluence of Montezuma Slough and the Sacramento/San Joaquin rivers to the Marsh's western edge. Extend this band of tidal marsh in an arc around the northern edge of the Marsh and blend naturally with the adjacent grasslands to provide maximum diversity of the upland ecotone, especially for plant communities.
- Restore a broad band of tidal marsh along the southern edge of Suisun Marsh and around Honker Bay, in large part to improve fish habitat.
- Continue the long-standing practice of managing diked wetlands primarily for waterfowl on the majority of lands within Suisun Marsh. Enhance these brackish marshes through protective management practices, to increase their ability to support waterfowl.
- Enhance moist grasslands with vernal pools on the periphery of Suisun Marsh,as well as riparian vegetation along the tributary streams.
- On the Contra Costa shoreline, restore full tidal action to many of the marshes that currently are diked or that receive muted tidal flow.
- Incorporate broad transition zones to foster a higher diversity of plant communities and associated animals.
- Provide buffers to protect these populations from adjacent disturbance. Restore riparian vegetation along as many stream corridors as possible.

North Bay

- Restore large areas of tidal marsh and enhance seasonal wetlands.
- Manage some of the inactive salt ponds to maximize their habitat functions for shorebirds and waterfowl,and restore others to tidal marsh.
- Protect and enhance tributary streams and riparian vegetation,and preserve and restore shallow subtidal habitats (including eelgrass beds in the southern extent of this subregion).
- Restore tidal marsh in a band along the bayshore, extending well into the watersheds of the subregion's three major tributaries — the Napa River, Sonoma Creek, and the Petaluma River.
- Improve seasonal wetlands in the areas currently managed as agricultural baylands.
- Protect and enhance all of the remaining seasonal wetlands in the uplands adjacent to the baylands.

Central Bay

- Protect and restore tidal marsh,seasonal wetlands, beach dunes, and islands.
- Restore natural salt ponds on the East Bay shoreline.
- Protect and enhance shallow subtidal habitats (including eelgrass beds).
- Protect and enhance tributary streams and riparian habitats.
- Restore tidal marshes wherever possible, particularly at locations that abut streams and at the upper reaches of dead-end sloughs. Encourage tidal marsh restoration in urban areas.
- Pursue opportunities to restore relatively small tidal marshes and other habitats, as topography and urban and industrial development limit the potential for large-scale habitat restoration in the Central Bay. Even small,disconnected patches of tidal marsh would provide habitat islands for migrating native wildlife species and improve overall habitat conditions. Even the smallest restoration efforts should try to incorporate transitions from intertidal habitats to adjacent uplands, as well as upland buffers, and to protect shorebird roosting sites.

PROJECT IN ACTION

Urban Marsh Restoration at Herons Head Park

Heron's Head Park, formerly known as Pier 98, is an urban greening project in its most dramatic form — ecological restoration of valuable shoreline property in an economically depressed neighborhood in one of the Bay Area's most populated cities. The park is located on a man-made peninsula created by the Port of San Francisco between 1970-1977 — via the placement of fill materials and construction debris — with the intent of providing either a container shipping terminal or the southern terminus of an additional Bay Bridge span. Work was never completed, and over time subsidence and inundation created three acres of tidal salt marsh along its southern shore. Enhancement of the existing wetlands and creation of five acres of new tidal salt marsh was completed in spring 1999.

The chosen design created new wetlands and a network of intertidal channels by removing fill soils and grading. Important design features are two small bird loafing and nesting islands that also provide refuge from high tides and predators, and a buffer from uplands areas. To create the refugia islands, the design took advantage of existing serpentine mounds placed there during construction of Highway 101. Naturally occurring serpentine contains high concentrations of trace minerals that can actually control invasive weedy plants.

The design also preserves and reinforces a unique assemblage of intertidal ponds that were essentially created by the fill and construction debris used to build the site. These ponds fill up with incoming flows on the higher tides and hold water during the outgoing tides, providing valuable bird habitat. In addition, the design enhances the newly-created transition zone between the wetland and upland areas. A local gardening group has initiated seed collection and propagation of transition zone plant species, many of which have become rare in the Bay Area as their habitat has been eliminated along with the salt marsh habitat.

In addition to ecological benefits, the Heron's Head Park design presents a rare piece of undeveloped shoreline — with established fishing and birdwatching opportunities — to a community which has little access to open space nearby. The design includes a new fishing pier, which provides a safe public fishing area while controlling damage to habitat and disturbance to wildlife. Local fishermen have long used the site, accessing areas adjacent the warm water P.G.&E. power plant outfall by walking through the wetlands.

The newly improved Heron's Head Park has and will provide myriad opportunities for community participation in wetlands enhancement. During the past year, more than 300 students, teachers, and community residents have participated in public programs at Heron's Head Park. In the future, the Port and the San Francisco League of Urban Gardeners will continue to educate community members and local students about natural resources conservation issues and techniques, while propagating, planting, and maintaining transition zone plants; City College of San Francisco will develop curricula around wetlands monitoring, including on-site activities for pre-kindergarten through college level courses; and the Southeast Alliance for Environmental Justice will hire and train local residents to lead public programs at Heron's Head Park (Levanthal, SOE Poster, 1999).

Participants: Port of San Francisco & San Francisco League of Urban Gardeners

Consultants: Levine-Fricke, AGS Inc., Keller-Mitchell, Inc, and Noble Consultants

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South Bay

- Restore large areas of tidal marsh connected by wide corridors of similar habitat along the perimeter of the Bay.
- Intersperse several large complexes of salt ponds, managed to optimize shorebird and waterfowl habitat functions, throughout the subregion,and restore naturalistic, unmanaged salt ponds on the East Bay shoreline.
- Provide and preserve natural transitions from mudflat through tidal marsh to adjacent uplands, wherever possible. Protect and improve adjacent moist grasslands, particularly those with vernal pools, for wildlife.
- Protect and restore riparian vegetation and willow groves wherever possible — see also p.22 (Goals Project, 1999).

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NEW SCIENCE

Ecological Design Principles

The Goals Project recommends use of the following ecological design principles in bayland restoration plans.

- Center tidal marsh restoration, where possible, around existing populations of threatened and endangered species.
- Include restoration of tidal marsh along the salinity gradients of the Estuary and its tributaries.
- Emphasize restoring tidal marsh along the Bay edge and where streams enter the baylands.
- Provide natural features, such as pans and large tidal channels, within tidal marshes.
- Reestablish natural transitions from tidal flat through tidal marsh to upland, and between diked wetlands and adjacent uplands.
- Provide buffers on undeveloped adjacent lands to protect habitats from disturbance.

PERSPECTIVE

EFFECTS OF THE GOALS PROJECT

Joshua N. Collins
San Francisco Estuary Institute

The Bay Area Wetlands Ecosystem Goals Project has provided an answer to the question: how much of what kinds of wetlands are needed where to restore a healthy bay system? The answer emerged through a long examination of the ecological past, the present, and change. The answer is large-scale restoration and enhancement of the baylands in all four subregions, South Bay, Central Bay, North Bay and Suisun, in ways consistent with natural processes that control habitat evolution and maintenance. The project has also provided a venue for improved communications among environmental scientists working in the baylands.

The prospect of such an effort raises the next big question, how should the ideal be achieved? This is a political question with technical underpinnings.

All the technical questions relate to the central concept of the baylands as the transition between the bays and the uplands. Although this concept has been stated many times in the past, it is premiered as the central concept of the Goals Project. The focus provides a new view of the Estuary as a complex of many estuaries, with ecologically significant gradients of salinity and tidal effects running up and down every tributary creek and river. We can no longer view the baylands as just the edge of the bay, they are also the edge of watersheds. The Goals Project is calling attention to watersheds as the source of many environmental problems and solutions for the baylands and the Bay. Many technical questions arise from this new view. For example, will implementation of the Goals recover threatened and endangered species; will it increase tidal flushing and thus improve navigation; will it improve water quality; will there be enough sediment to build tidal marshes; do we start with tidal marsh restoration or diked bayland enhancement or both; and how big should projects be?

These are just a few of the many technical questions that project participants have raised. They seem to provide some detail on two larger questions: what is the relationship between level of baylands management or restoration effort and level of ecological function, and how is this relationship affected by natural processes and people in the attending watersheds. In simpler terms, we might ask, what are the cost breaks that make restoration and enhancement affordable, and what are the ecological thresholds that mean success?

The only way to answer these questions is to get started with a program of implementation that includes monitoring and research, such that we can learn by doing. There is a need to think big, move forward with measured steps, and question our assumptions and objectives all the way.

In the coming years, the San Francisco Estuary Institute will be working with other sources of technical help to develop a regional plan of baylands research and monitoring that can support the restoration and management of the baylands (Collins, SOE, 1999).

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TERRESTRIAL SPECIES

THE IMPORTANCE OF THE WETLAND-UPLAND INTERFACE

Lynne Trulio, San Jose State University

The terrestrial vertebrate species living at the edge of San Francisco Bay are important elements of the Bay's ecological functioning. The *Status and Trends Report for Wildlife* of the San Francisco Bay Estuary (1992) lists over 380 terrestrial vertebrates — amphibians, reptiles, birds and mammals — associated with the Bay in the counties immediately adjacent to the Bay and Delta. Although this diversity is impressive, since Europeans arrived many species have declined severely in abundance. At least 10 vertebrates have been extirpated from the region,including sea otters, pronghorn antelope, elk and California condors. Two species, the grizzly bear and grey wolf, have been eliminated from the entire state. The reintroduction and recovery of these species is a major restoration challenge.

People have also introduced at least 17 vertebrates to the region. Some, such as the wild turkey and ring-necked pheasant, fit into the local ecology without major ill effects. Others disrupt the ecology and cause havoc for native species. Exotic red foxes, for example, are known predators on endangered clapper rails and other ground nesting birds. Competition and predation by the non-native bullfrog has been one factor leading to the threatened status of the red-legged frog, once an abundant species.

Bay-Delta terrestrial species live in habitats from tidal salt marshes and riparian zones to grasslands and oak woodlands. The great majority of these species also use or depend upon transitional habitats, or ecotones, that connect the Bay-Delta wetlands with upland ecosystems.

Animals crossing this boundary connect wetland and upland ecosystems through interactions such as predation and competition. An ecotone is a dynamic gradient between adjacent ecosystems across which materials and energy flow. Definitions of ecotones emphasize their transitional qualities and dynamic nature.

Approximately half the San Francisco Bay edge is surrounded by Holocene era alluvial soils, which create a wide transitional zone between the tidal Bay-Delta and upland, terrestrial habitats. Alluvial soils support moist grassland/vernal pool habitats and riparian zones, two important Bay ecotones. Another vital transitional zone is the narrow high marsh area connecting the tidal zone and the terrestrial upland. According to data from the San Francisco Estuary Institute Eco-Atlas, approximately 74% of the alluvial soil habitats adjacent to the Bay have been lost (see table). Many restoration projects have been undertaken in riparian habitats, but moist grasslands have received very little restoration attention.

Ecotones are well known for their high biodiversity. They are very valuable to wetland species as they provide refugia from high tide events. Lack of protected high ground next to marshes has contributed to declines of rare salt marsh species such as black rails, clapper rails and salt marsh harvest mice. Transitional habitats pro-

NEW SCIENCE

Rail Habitat

Numerous Bay Area tidal marsh restoration projects attempt to provide habitat for the endangered California clapper rail, a largish, brown, secretive, pear-shaped bird whose Bay population is now estimated at only a little over a thousand birds (see p.12). High-quality clapper rail habitat needs full tidal circulation; a predominant pickleweed marsh with cordgrass, gumplant, and other high marsh plants; high marsh cover; and a well-developed system of tidal sloughs. Marsh restoration sites should be as large as the Dumbarton Marsh (118 ha) or Mowry Marsh (164 ha). Marshes should be within 1-3 km of each other, the distance clapper rails are known to disperse. Power lines, poles, and buildings provide perches for raptors and should be removed from restoration sites where possible. Because rubble piles and other structures can house Norway rats and feral cats, which prey on the rails, these should also be removed from marsh areas. Rails are susceptible to human disturbance, and recreation and maintenance activities should be carefully considered before being permitted on restoration sites. Restoration should also include management of non-native vegetation and predators like the red fox and feral cats; however, in the long run, only high-quality habitat will ensure an increase in clapper rail numbers. The restoration of Bair Island, a 1,600-acre former salt pond, holds promise for rail recovery because of its large size and proximity to another rail population on nearby Greco Island (Albertson & Evens, 1998).

The black rail also deserves the attention of restoration planners. Black rails need refuge from high-tides, at high elevations within the marsh where there is still tidal influence. Since connectivity with existing habitat could allow for better rail dispersal, restoration of smaller sites adjacent to occupied marshes such as the north shore of San Pablo Bay, and the entire south shore of Suisun Bay — particularly 5,000-plus acres near the Concord Naval Weapons Station — holds the greatest potential. Black rails are particularly sensitive to alterations in freshwater inflows, and rely on elevations just above the mean high water line, which are a little less saline and support a food web of terrestrial organisms the rails seem to rely upon (Evens 1997).

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vide food chain support to upland species, such as the burrowing owl and red-tailed hawk,and the presence of a wide buffer may prevent upland predators from foraging heavily in tidal marshes. Connecting upland and wetland ecosystems is considered critical to the proper functioning of the Bay-Delta (Goals Project, 1999). Over 80% of the Bay-Delta's special status species use or depend upon ecotonal areas.

Diking, filling, and dredging to support agriculture, industry and urban uses have all resulted in the loss of connections between the wetlands and uplands. A wide range of terrestrial species would benefit from the restoration of moist grassland, riparian and high marsh ecotones (see below). The recovery of these listed species depends on our ability to restore high quality connections between tidal marsh or stream zones and upland grasslands and woodlands.

What restoration work has been undertaken to help preserve and recover terrestrial species at the edge of the Bay? Numerous riparian zone and salt marsh restorations, particularly mitigation projects, have been implemented since the 1970s, when environmental regulations were enacted. Many of these projects are designed to restore habitat for rare or endangered species. However, there are no clear data on the overall results of these habitat restoration projects. Lack of monitoring has constrained our understanding of what procedures result in success or failure.

Monitoring of South San Francisco Bay salt marsh restoration projects, for example, has not been extensive enough to determine the effects on the clapper rail or salt marsh harvest mouse. However, habitat enhancement of the New Chicago Marsh in Alviso for the salt marsh harvest mouse has proven successful over the past 10 years. An example of successful clapper rail habitat restoration is the Avocet Marsh in Newark,undertaken by the staff of the Don Edwards San Francisco Bay National Wildlife Refuge. In 1985,salt marsh restoration was begun at a 100 acre former salt crystallizer pond next to Refuge Headquarters. In 13 years, this barren site was transformed into a functioning salt marsh that supports at least 5 clapper rails, 2 pairs and 1 single bird.

Past and Present Habitat Acreages for the San Francisco Bay Estuary:

Adjacent Habitats (data from Goals Project, 1999)

Habitat Type	Historical (ca. 1770-1820)	Present (ca. 1997)	% Change
Moist Grassland	60,487	7,474	-88%
Grassland/Vernal Pool	24,070	15,038	-38%
Riparian Forest	2,350	737	-69%
Willow Grove	2,547	37	-99%
Total	89,455	23,286	-74%

Since at least 90% of the original tidal salt marsh wetlands — cordgrass-pickleweed wetlands — have been destroyed, replacement of this ecosystem is a critical goal of restoration efforts around the Bay. However, we have begun to realize that species dependent on tidal marsh wetlands also require high tide escape zones and ecotonal buffer areas, if populations are to persist.

Several projects are now including transitional habitat to connect salt marsh restorations with adjacent uplands, including large projects at Oro Loma in Alameda County, Montezuma Wetlands in the Delta, Hamilton Airfield in Marin County (see p.49) and the Catellus Corporation restoration mitigation in Alameda County.

Much more can be done to restore terrestrial species. Planners and communities can do a better job preserving and restoring species by following the specific recommendations of the 1999 *Habitat Goals* report and other ecological planning documents. Communities should require that projects move out of the flood plain and high tide zones, rather than building right up to levees. Staying out

Terrestrial Species at the Edge

Some Species using Moist Grassland/Vernal Pool Ecotones

- CA Tiger Salamander (FC,SSC)
- Western Spadefoot Toad (SSC)
- SF Garter Snake (FE, SE)
- Short-eared Owl (SSC)
- Burrowing Owl (SSC)
- Snowy Plover (FT, SSC)
- Herons/Egrets
- Waterfowl/Shorebirds

Some Species using Riparian/ Willow Grove Ecotones

- Western Pond Turtle (SSC)
- CA Red-legged Frog (FT, SSC)
- Swainson's Hawk (ST)
- Long-eared Owl (SSC)
- Bank Swallow (ST)
- Willow Flycatcher (FE, SE)
- Salt Marsh Yellowthroat (SSC)
- Neotropical Migrants

Rare Vertebrates that Require Wetland/High Tidal Marsh Ecotones

- Salt Marsh Harvest Mouse (FE, SE)
- Ornate Shrew (FC1,SSC)
- Suisun Ornate Shrew (FC1,SSC)
- Salt Marsh Wandering Shrew (FC1,SSC)
- Alameda, San Pablo, Suisun Song Sparrows (SSC)
- California Clapper Rail (FE, SE)
- California Black Rail (FC1,ST)
- California Least Tern (FE, SE)

FT, FE = Federally Threatened, Federally Endangered
FC1 = Federal Candidate Species
ST, SE = California State Threatened, CA State Endangered
SSC = California State Species of Special Concern

of the flood plain reduces the chances of property damage and allows the restoration of rare riparian and seasonal wetland habitats. Planners can also work to include habitats for specific species in urban landscaping. Using native plant species and allowing important local species such as ground squirrels and voles to survive will provide more habitat for rare and declining species and will improve overall biodiversity.

REHAB ADVICE

General Terrestrial Species Recovery

- Realize that all restorations are experiments. Our predictive power is very low and systems may have multiple endpoints.
- Base restoration targets (measures of success) on the best model sites, historical information and modeling.
- Develop target ranges based on natural variability, measurement variability, multiple endpoints and uncertain constraints.
- Consider constraints on achieving ecosystem functioning/species recovery and modify success goals accordingly. Typical constraints are adjacent land uses (flood, fire constraints), human uses of site, site history (fill, toxics, draining, non-natives), lack of land (or money to buy it), lack of full complement of species, incomplete scientific data.
- Design experiments to test the reasons why species do or do not respond to restored sites.
- Monitor for long periods of time to determine long-term effects of restorations on species use, behavior, abundance and productivity.
- Monitor parameters to determine both species and ecosystem recovery.

Species-Specific Recovery

- Preserve remaining rare species habitats and transition zones.
- Target requirements of specific organisms within context of full habitat restoration.
- Restore as much habitat as possible, including transitions connecting upland and wetland ecosystems.
- Provide patches of habitat, as close together as possible, if contiguous habitat is not available.
- Find ways to connect the hydrology between patches.
- Recognize that levees create a hard edge around habitats that may be difficult for wildlife to cross.
- Manage remaining habitats to include gradients, habitat mosaics, ecological processes and biodiversity (Trulio, SOE, 1999).

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PROJECT IN ACTION

Habitat Mix at Hamilton Airfield

The Hamilton Wetlands Restoration Project will restore a diverse mix of wetland habitat to over 900 acres of diked baylands at the former Hamilton Army Airfield in Novato, Marin County for endangered and other wetlands species. The project will also beneficially reuse up to 11 million cubic yards of clean material from Bay dredging projects.

A conceptual design has been prepared for the restoration project that is based on the physical characteristics of the site and lessons learned from past restoration projects, including the nearby Sonoma Baylands Project. The design is for a landscape that gradually slopes from uplands to the Bay — much like the historic shoreline did — supporting large expanses of tidal and seasonal wetlands. To accomplish this, levees will be constructed around the subsided site to protect adjacent properties from flooding. The site will then be filled with clean material from Bay dredging projects to construct the upland and seasonal wetlands site features and to speed the formation of tidal wetlands. However, the material will be placed low enough in tidal areas to allow the wetlands to form naturally on sediments carried in on the tides. Salt pannes, a feature of historic Bay wetlands that flood only on spring tides, will be created at the margin of the tidal areas. In fact the project's design centers around developing transitional habitat areas such as seasonal wetlands and tidal pannes that will persist for a significant number of years and provide a continuous transition in habitat type from tidal areas to the adjacent uplands. These transitional areas will also serve as high tide refugia for local wildlife.

The result will be one of the largest contiguous tidal wetlands in the Bay. Two channels to the Bay, each over 200-feet wide, will restore tidal waters to the site. Plants and animals will colonize as the sediment-rich Bay waters build mudflats, and the ebb and flow of the tides cut a dense network of channels across the spreading tidal wetlands. The tidal areas will provide habitat for Bay fish species, including young endangered salmon making their journey to the ocean. The marsh channels will also be used by the endangered California clapper rail, while the pickleweed in the high marsh will be home to the endangered salt marsh harvest mouse. All the wetlands will be heavily used by a variety of shorebirds and waterfowl. Although the public will not be allowed into the sensitive habitat areas of the marsh, the Bay Trail will traverse the southern levee of the site and an overlook of the entire wetlands area will be provided on nearby Reservoir Hill (Goldbeck, SOE Poster, 1999).

Participants: California Coastal Conservancy, S. F. Bay Conservation and Development Commission, San Francisco District, U.S. Army Corps of Engineers, and Hamilton Restoration Group.

Design Consultants: Woodward-Clyde, Philip Williams & Associates, H.T. Harvey & Associates, and Eric Polson

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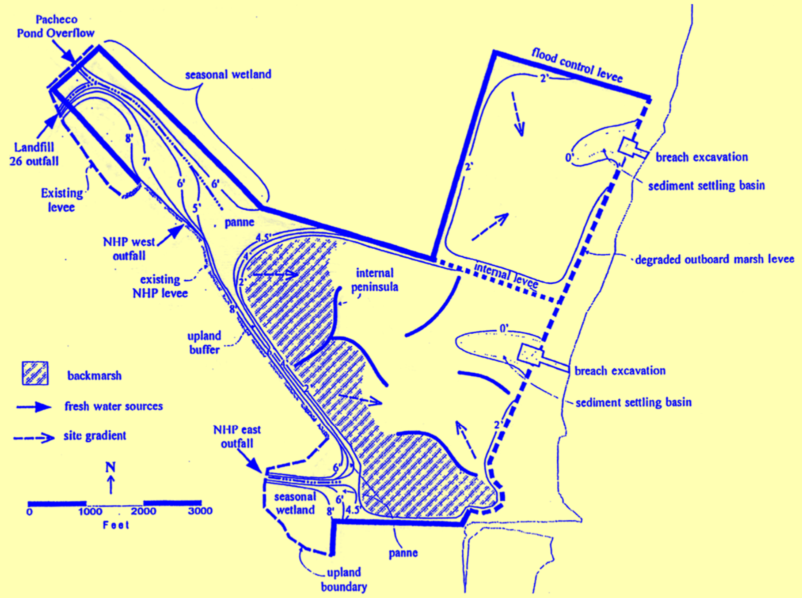
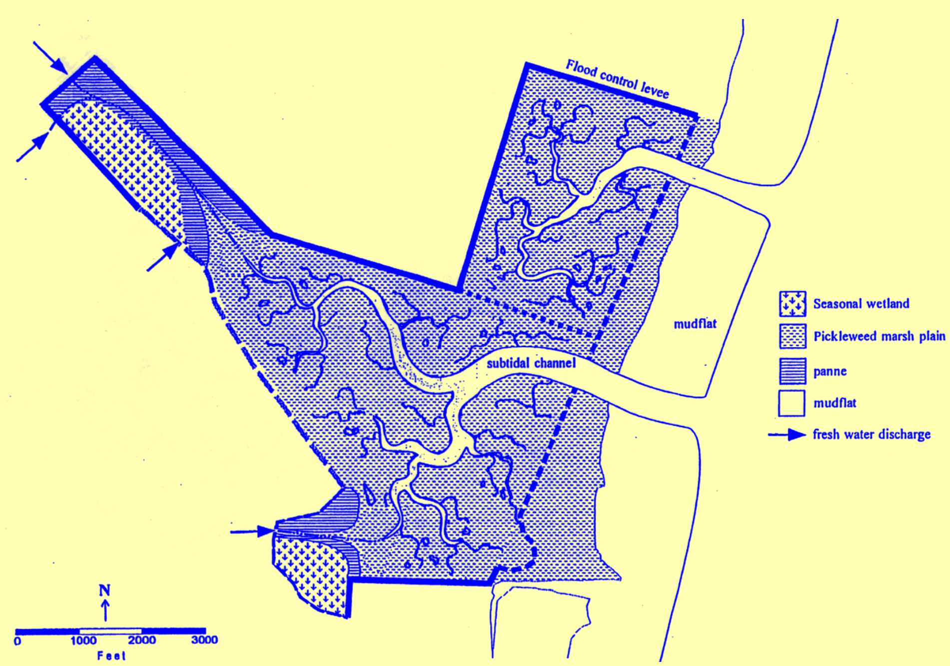
Initial Conditions:
Site Template Year 0



Evolution at Year 50



RARE PLANTS

Brenda Grewell, University of California, Davis

Emergent marsh plant communities are the visible defining elements of the San Francisco Estuary's tidal wetlands, and encompass a unique diversity of flora. Rare plants are important members of these communities and should be considered in conservation and restoration planning. Endangered tidal marsh plants include soft-haired birds beak (*Cordylanthus mollis ssp. mollis*), Suisun thistle (*Cirsium hydrophilum*) and Mason's lilaeopsis (*Lilaeopsis masonii*). Two other important marsh plants — California sea-blite (*Suaeda californica*) and California saltbush (*Atriplex californica*) — are now locally extinct. If we are to restore the integrity of our marshes, we should consider historic assemblages of plants including those which are locally extinct.

As many as 61 additional tidal-wetland-dependent species have been identified by the California Native Plant Society as plants of concern due to habitat fragmentation and degradation. Though no regulatory protection exists for many of these species, some of their habitat needs may be addressed in the U.S. Fish and Wildlife Service tidal marsh recovery plan.

Among the Estuary's rarest plants is the endangered Suisun thistle, a species occurring solely in Suisun Marsh. Only two populations of this thistle, which grows along small tidal creeks near the high marsh border, remain in existence today. Another rare species is the endangered soft-haired bird's beak. This annual plant survives the long, harsh season in the high marsh through parasitic connections to common marsh plants like saltgrass and pickleweed which contribute water and solutes needed for growth. Historically, soft-haired birds beak occurred from Antioch to the Petaluma marsh. Today it is restricted to ten populations between Central Suisun Marsh and Point Pinole. A third rarity is the state-listed Mason's lileaopsis — a diminutive member of the carrot family that has a fascinating ecology. This plant is specially adapted to life in the action zone, growing where waves erode and slump mud banks between the Delta and Mare Island. Tides transport floating propagules from this plant that have been dislodged by bank erosion,which may reestablish on other exposed banks. To maintain these metapopulation dynamics, restoration planners must consider providing extensive reaches of suitable habitat.

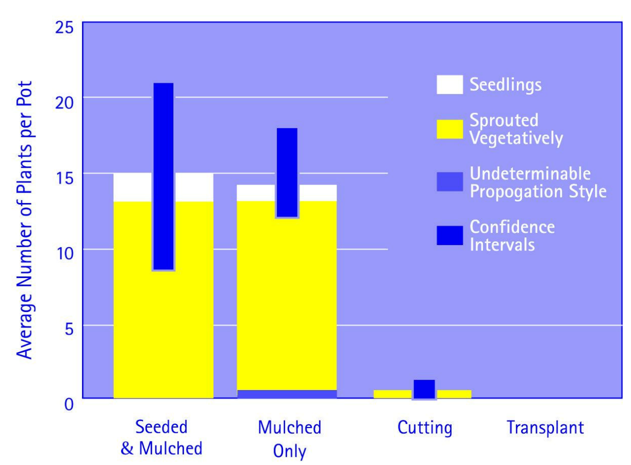
The Estuary's endangered tidal marsh flora have not always been rare. In most cases, these species are locally abundant but greatly reduced in range due to the diking, filling and fragmentation of tidal marshes throughout the Estuary. Such disturbances not only directly remove habitat and cut off natural linkages to fish,birds and other parts of the food web, but also limit seed dispersal and pollination processes. In addition,human alteration and management of the Estuary's hydrologic processes have impacted rare plants by reducing natural variation in their environment. Natural variability in climate, Delta outflow, watershed inputs and marine tides all affect the amount of flooding experienced by wetland plants.

NEW SCIENCE

Pickleweed Propagation Techniques

Research comparing various plant propagation and restoration treatments on the establishment of pickleweed (*Salicornia virginica*) in severely disturbed habitat showed substantial differences in effects. The research resulted from the U.S. Navy's decision to convert two parking lots to intertidal, brackish water marshes at the Weapons Support Facility Seal Beach Detachment Concord, as partial mitigation for a pier expansion project. The research documented the effects of two restoration treatments on the establishment of pickleweed: (1) enriching the soil with organic material (in this case, commercial compost), and (2) placing pickleweed material on the soil surface, i.e., mulching with pickleweed.

Pickleweed Growth Versus Planting Techniques



Results of a pilot greenhouse study showed substantial differences in the success of different propagation techniques tested (see chart). Transplants, cuttings, and seeding were rather ineffective at establishing recruitment, but pickleweed mulch placed on the soil surface sprouted readily. In the field, treatments and controls were applied to randomly selected plots in the former parking lots in fall 1998 and spring 1999. To prepare the lots, asphalt had been removed and the soil texture tested and enhanced with fine-textured material dredged from a nearby marina (soil under the asphalt was rocky and sandy, whereas soil in estuarine marshes is naturally more finely textured). Treatments then applied to the test sites were enriching the soil with compost (by rototilling), mulching with pickleweed, a partial control consisting of rototilling without adding compost, and a full control. Monitoring will continue seasonally, but visual inspections of the study plots suggest distinct treatment effects (Disney & Miles, SOE, 1999).

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While salinity, hydrology and soils are often considered the determining factors in the establishment and zonation of tidal marsh plant communities, biological interactions also play a significant role. For example, several invasive species now challenge efforts to restore floristic diversity. Atlantic cordgrass is changing the primary functions and structure of tidal marshes as it traps sediment and raises marsh elevations (see p. 54). Meanwhile *lepedium latafolium*, the white flowered peppergrass, is actively displacing the endangered Suisun thistle and the rare Jepson's Delta tule pea. The peppergrass' close association with endangered species presents tremendous control challenges.

Despite such challenges, some of today's plant populations have been intact since the mid 1800s, before marshes were diked. Unlike birds and fish, most of these plants have not had the mobility to move to more suitable spots as habitat was lost or degraded. For this reason, rare plants are perhaps the best barometers of health in the Estuary and its habitats. Any work to restore the ecological integrity of the Bay's marshes must consider historic assemblages of plants, including species which are now locally extinct.

The most significant limiting factor to the successful sustainable restoration of the Estuary's historic floristic diversity is a basic lack of applied research yielding critical ecological data. If the historic landscape is to be our restoration guide, we should not miss the opportunity to learn more about these key species. Millions of dollars are spent researching fish and waterfowl each year, while in the past ten years there have only been a few small studies of rare plants. People's perspective on what are the biggest human impacts on the Estuary often comes directly from what's been studied most — namely fish. Tidal marsh plants are also directly affected by water management and should not have to grow gills to deserve attention.

REHAB ADVICE

- Conserve existing populations of rare plants.
- Give priority to restoration opportunities which link tidal marshes to alluvial soils, seeps, and drainages. The current tendency to create tidal marsh as indented pockets within levee systems separated from the Estuary's historic margins will not support historic floral diversity.
- Enhance the complex soil landscapes that support floristic diversity. Substrate and slope complexity are critical to restoration success. Many rare marsh plants and associates depend on the soil characteristics of peat-rich marsh soils formed from plant decomposition, or salinized and weathered upland soils where highly variable soil texture occurs. For this reason, other types of soils, such as imported mud or sandy material dredged from the Bay bottom, should only be used selectively in marsh restoration.
- Experiment with reintroducing rare or extinct plants. Be sure to distinguish between reintroductions of plants into habitats where they have been extirpated and translocation into potentially suitable habitats. Translocation has not been widely successful.
- Don't rely solely on today's remaining tidal marshes as perfect references to historic conditions. Plant communities and interactions with the environment, in particular, may be quite altered.
- Launch a long-term census of plant species. Link and expand census studies with research into the life history of rare plants and into the relationship between population size and extinction probability. Large scale environmental variation and dispersal rates may be more important determinants to extinction than plant population (Grewell, SOE, 1999).

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NEW SCIENCE

Salt Marsh Dodder: Parasite or Helpmate?

Keystone species such as the salt marsh dodder may help us link population and ecosystem needs. This orange trailing vine is a parasite which is not capable of photosynthesis and thus remains completely dependent on its host plants for nutrients and water supply. Studies (Pennings & Callaway 1996) at Carpenteria salt marsh suggest that this plant can suppress competitive dominance, open up spaces and gaps for rare plants, and promote cycles of biodiversity. During the past two years, researchers from U.C. Davis experimentally removed salt marsh dodder from Bodega Marine Lab's salt marsh reserve. The effect on the initial and primary host plant was not surprising — growth and reproduction were significantly suppressed. The effect of this holoparasite removal on the rare hemiparasitic Point Reyes bird's beak was more surprising — bird's beak performed better when directly interacting with dodder. Researchers are now examining details of the population dynamics of these parasitic plant interactions and the full plant community response to dodder removal. Such preliminary results point to the need to consider rare plant recovery needs in a community context (Grewell, SOE, 1999).

MIGRATORY BIRDS

Gary Page, Point Reyes Bird Observatory

More than 80% of the historic tidal salt marshes and 40% of tidal flats in the San Francisco Bay Estuary have been lost to development or altered by diking. The tidal flats that are left, as well as the salt ponds which replaced marsh and mudflats, are important habitats for migratory and wintering shorebirds and waterfowl.

Shorebird Use of Tidal Flats Versus Salt Ponds*

Shorebird	Tidal flat		Salt ponds	
	Fall	Spring	Fall	Spring
Black-bellied plover	94	95	<1	<1
Marbled godwit	91	96	2	<1
Willet	90	87	2	3
small sandpipers	90	94	2	1
dowitchers	76	92	10	<1
American avocet	37	32	52	25
Snowy plover	16	40	69	51
Black-necked stilt	4	7	86	60
Red-necked phalarope	<1	<1	99	93

* Median percent of shorebirds on San Francisco Bay tidal flats and in salt ponds from preliminary analyses of PRBO data. Source: L. Stenzel and G. Page unpublished data.

Rehabilitation of historic tidal marshes is widely promoted as a means of increasing populations of species native to these wetlands. The great changes to the Estuary landscape, however, may preclude returning the ecosystem to historic conditions, nor may that be the most desirable goal. Restoration of tidal salt marshes is a developing science, and widespread success in restoring endangered species populations through such projects is not guaranteed.

What is clear is that man-made wetlands such as salt ponds now function as critical wintering and migration habitats for shorebirds, waterfowl and other waterbirds in the Pacific Flyway. Many species adapted to these new habitats over time, and those now favoring the salt ponds include ruddy ducks, avocets, stilts, snowy plovers and phalaropes. Current use of the Bay by phalaropes, for example, is likely much higher than it was historically due to creation of suitable new salt pond habitat here and lost habitat elsewhere. Tens of thousands of Wilson's and Red-necked phalaropes use the Bay's salt ponds in the fall. Likewise, 90% of the ruddy ducks visiting the Bay use the salt ponds. Many of the 20,000-25,000 wintering American avocets and black-necked stilts also forage heavily in the salt ponds. Conversion of these habitats to salt marshes will have negative consequences for many of these waterbirds.

REHAB ADVICE

- Acknowledge that we can't turn back the clock for San Francisco Bay.
- Remember — in the rush to restore tidal marshes — that we also need more mudflats for waterbirds.
- Preserve salt pond habitats. If the Bay's salt pond habitats are all converted to tidal marshes, many birds will have no place left to go (Page, SOE, 1999).

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NEW SCIENCE

Diving Ducks Need Salt Ponds

Researchers examined midwinter waterfowl surveys from 1988 to 1999, before and after the end of salt production in the North Bay in 1992, to examine how waterbird use changes with conversion of salt ponds. Overall waterfowl numbers in the salt ponds fluctuated from 6,500 to 36,000 birds during the past decade with no significant trend. However, we found major changes in different foraging guilds. Dabbling ducks increased, while diving ducks decreased from 32,000 in 1989 to 3,600 in 1997. The species with the largest decline was the canvasback, which decreased 75% from 8,000 to less than 2,000 individuals. Change in waterbird numbers may be attributed to reduced water levels in the ponds, which favors dabbling ducks feeding in shallow surface water, rather than diving ducks feeding on benthic invertebrates in deeper water. Salt ponds provide diving birds with feeding areas, impoundments for roosting, and large, undisturbed areas of open water for safely taking flight.

Converting from one wetland habitat type to another may benefit some species at the expense of others. These recent analyses suggest that densities of diving birds in the winter and spring are four times greater in salt ponds compared with bayland wetlands. Thus, a far larger area of bayland wetlands may be required to compensate for the loss of salt ponds to maintain current diving bird populations. Future research efforts should be directed at developing suitable types of managed wetlands to replace values provided by salt pond systems and to maximize the value of the saline ponds that are developed from old salt ponds (Takekawa, Pers. Comm., 2000).

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Tringa Habitat

"Tringa" is the genus of greater and lesser yellowlegs and solitary sandpiper, three of eight species of shorebirds that need localities for rest, shelter and forage during migration periods and in the winter. Most of these species will not forage in tidal flats. Tringa habitat is fresh or lightly brackish water with grassy edges such as found in deltas, higher bayshore elevations, sewer ponds, creek mouths and some impounded wetlands, managed or natural. None of these species are agency listed but none are common here because their habitat here has been dwindling for decades. Most are detected here only during the fall migration with virtually none passing during the spring. Perhaps the manipulation of estuarine shores, along with the normal input of winter rains, eliminate enough Tringa habitat to alter migration routes. During the migratory periods, these species of birds greatly benefit when they can find suitable habitat in creek or river deltas or the drawn-down ponds of managed wetlands (Stallcup, SOE, 1999).

NEW SCIENCE

North Bay Rates and Patterns of Wetland Restoration

The Sacramento-San Joaquin Delta Breached-Levee Wetland Study (BREACH) is a CALFED-supported, interdisciplinary research effort comparing historically breached-levee wetlands to natural (unleveed) wetlands in order to better predict the feasibility, patterns and rates of restoration to natural ecological function. This map offers a preliminary inventory of all potential reference and naturally or intentionally breached-dike wetlands being considered by the BREACH program for a network of approximately 12 study sites in Suisun and San Pablo bays. The final study sites will be selected to represent likely points in trajectories between young (relatively unvegetated) and mature wetlands. Reference sites will be selected to characterize expected "restoration endpoints," with priority given to sites that have existing data or are designated for long-term protection, research and management (e.g., new S.F. National Estuarine Research Reserve sites). Sites are likely to be distributed in "clusters" associated with two to three sub-estuary watersheds (e.g., Petaluma, Sonoma, Napa rivers, Suisun Slough). As of summer 2000, researchers had identified 30 breached-dike sites, and 15 reference sites, and gathered preliminary information about each site. The final site selection will occur in summer 2000 (Simenstad et al., *IEP Newsletter*). Suggestions for additional sites, or information on sites listed in this inventory, are encouraged and may be forwarded to Michelle Orr at mko@pwa-ltd.com.

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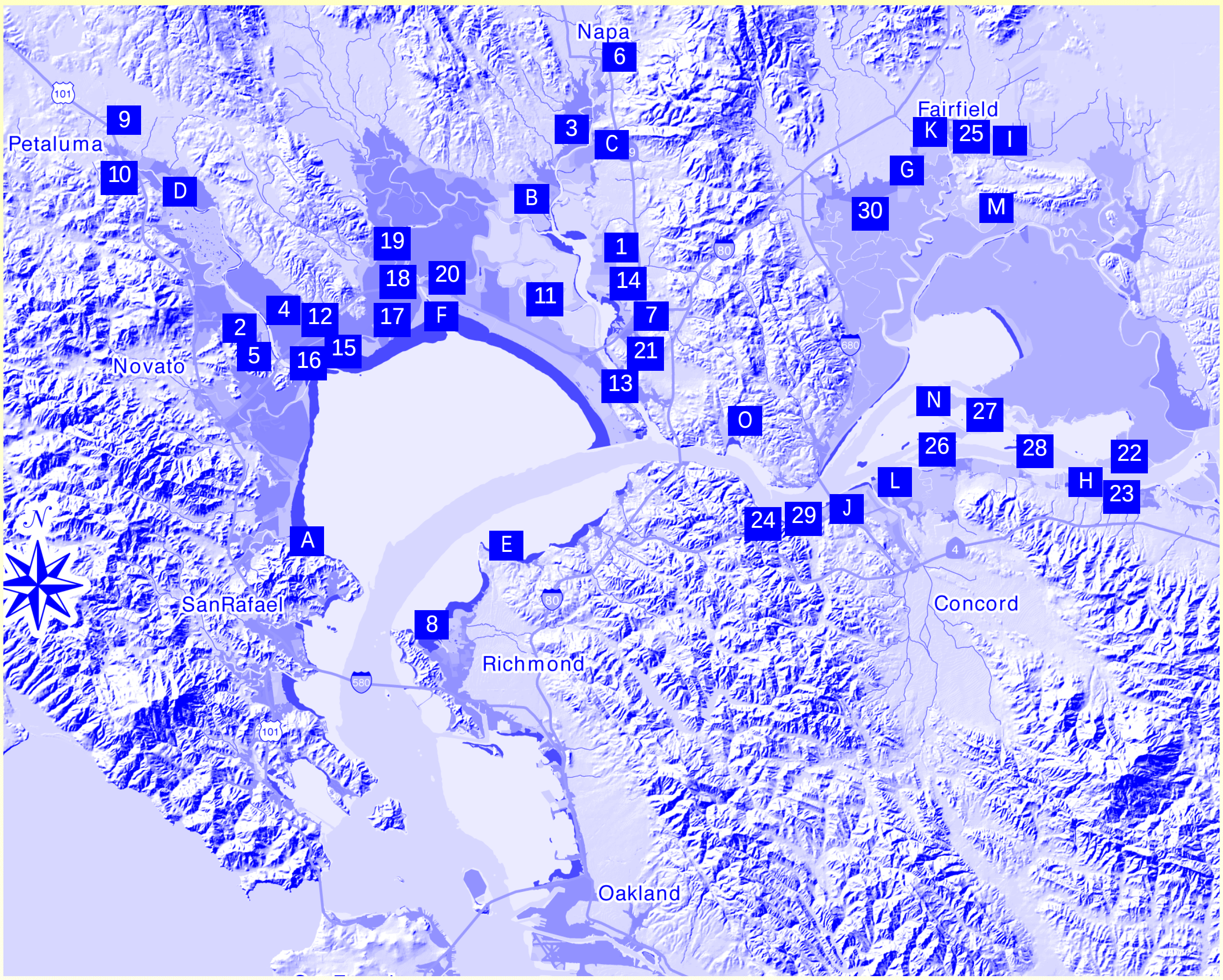

Source: Base map from EcoAtlas, SFEI

Map Key

Reference Sites
A. China Camp
B. Coon Island / Fly Bay
C. Fagan Slough
D. Petaluma River Marshes
E. Point Pinole
F. Sonoma Creek (Mouth)
G. Boyton Slough
H. Concord Naval Weapons Station
I. Hill Slough
J. Peyton Marsh
K. Peytonia Slough
L. Point Edith
M. Rush Ranch
N. Ryer (West)
O. South Hampton Marsh

North Bay Breached Sites
1. American Canyon
2. Bahia Lagoon
3. Bull Island
4. Carl's Marsh
5. Greenpoint
6. JFK Memorial Park*
7. Meadows Drive*
8. Nevada-Shaped Parcel
9. Petaluma River 1*
10. Petaluma River 2*
11. Pond 2A
12. Port Sonoma Marina
13. Pritchett Marsh
14. Slaughterhouse Point
15. Sonoma Baylands Main Unit
16. Sonoma Baylands Pilot Unit
17. Tolay Creek, Dickson Lagoon
18. Tolay Creek 1
19. Tolay Creek 2*
20. West End Duck Club*
21. White Slough

Suisun Bay Breached Sites
22. Chipps Island (West)
23. Concord Naval Weapons Station
24. Martinez Waterfront Marsh
25. Peytonia Slough Pond
26. Roe
27. Ryer (East)
28. Seal Island
29. Shell Oil Marsh North*
30. Sunrise Island

* Additional information is needed to confirm inclusion of these sites in the inventory.

INTRODUCED SPECIES

Tom Dudley, University of California, Berkeley

Non-indigenous species of plants and animals, introduced from other regions into California ecosystems in which they did not evolve through human activities, are now major threats to biodiversity and ecosystem function throughout the Sacramento-San Joaquin watershed, including many areas dedicated to the protection of native species and natural ecosystems. The majority of protected species in California are associated with wetlands and riparian areas, so interference by invaders can have serious implications for their survival and restoration of the estuarine ecosystem. Based on surveys of natural area managers throughout California, it is conservatively estimated that there are 142 non-indigenous plants and animals considered management problems in aquatic and riparian ecosystems of the state, 90% of which are present within our watershed (many others are present, but either too common for control or not sufficiently problematic to warrant concern).

Of these, 69 species are considered serious invasive pests, species known to directly threaten sensitive native species or to alter ecosystem characteristics. Besides interfering with declining native species through competition, predation and habitat degradation, these invaders also cause substantial economic damage, including increased fire risk, flood debris and erosion problems with giant reed (*Arundo*), or disruption of water delivery systems and of fisheries by Asian clams (*Corbiculafluminea*), water hyacinth (*Eichhornia crassipes*), and mitten crabs (*Eriocheir sinensis*).

High elevation headwater streams tend to be less prone to non-indigenous species impacts, presumably because physiological stress reduces the number of species that can tolerate the winter. Lower elevation headwater streams are invaded by numerous plant species, particularly those which form dense stands that choke out native species along stream margins, including Himalayan blackberry (*Rubusdiscolor*), English ivy (*Hedera helix*), Cape ivy (*Delairea* odorata), and periwinkle (*Vinca major*). In a few locations, purple loosestrife (*Lythrumsalicaria*), which has been so problematic in the eastern states, is present and is the subject of control programs. In other sites, saltcedar (esp. *Tamarixparviflora* in our region) has come to dominate streambanks and alter riparian dynamics throughout the West. In addition to bullfrogs and non-native trout, and a whole host of other exotic fish, crayfish also threaten natural ecosystems through their voracious, omnivorous behavior, and there are fears that the Chinese mitten crab may soon enter many smaller streams as it has done in Sonoma Creek, or invade sensitive vernal pools during high water periods.

NEW SCIENCE

Smooth Cordgrass Spread & Control

The proliferation of invasive smooth cordgrass (*Spartina alterniflora*) — and its hybridization with California cordgrass (*Spartina foliosa*) — could grossly alter the character of San Francisco Bay and now threatens numerous newly-restored tidal marshes and mudflats. This East Coast native was purposefully introduced to south San Francisco Bay about 25 years ago to promote wetland restoration, and has since spread by further plantings and seed dispersal by tides. Previous work suggested that smooth cordgrass was competitively superior to native California cordgrass, and that the two species hybridized. In 1997, researchers began a study to determine the spread of *S. alterniflora* and *S. foliosa* x *alterniflora* hybrids in California using DNA markers diagnostic for each species to detect the parental species and nine categories of hybrids. All hybrid categories exist in the Bay, implying several generations of crossbreeding. Researchers primarily found hybrids near South Bay sites of deliberate introduction of *S. alterniflora*. However, a few hybrid plants were discovered north of the Golden Gate. Where smooth cordgrass was deliberately planted, the marsh was composed of roughly equal numbers of smooth cordgrass and hybrid individuals, while the native species was virtually absent. Marshes colonized by water dispersed seed contained the full gamut of plant types with intermediate-type hybrids predominating. This proliferation of possibly highly fit hybrids could result in local extinction of native species. What is more, smooth cordgrass has the ability to grow both higher in the marsh and lower down the intertidal gradient than the native cordgrass, and thus to modify the estuary ecosystem to the detriment of native species and human uses of the Bay.

The genetic patterns observed by researchers provide general guidelines to curbing the spread of smooth cordgrass and its hybrids. Control efforts should focus on the complete extirpation of populations that contain few pure native plants since these populations export large numbers of hybrid seed. In addition, smooth cordgrass and hybrids could be selectively removed from native marshes that have not been heavily invaded. Other tactics, aimed at preventing new invasions, are to temporarily curtail opening new areas of unvegetated mud to the Bay, particularly in infested areas, since the populations of seedlings that establish are likely to contain huge numbers of hybrids. Also, uninvaded marshes should be regularly monitored to prevent invasion and only pure native cordgrass from uninvaded marshes should be used for restoration projects (Ayres, SOE Poster, 1999).

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Smooth Cordgrass Proliferation

Downstream in lower gradient floodplains, additional thicket-forming species have become abundant in the watershed, especially giant reed, which is increasingly the subject of local control efforts. Natural hydrological processes are thwarted, as these thickets promote excess sedimentation in some sites, while resulting in erosion and channel cutting in others because of their shallow root systems.

Invasive Species in Wetlands & Riparian Zones

	California	Watershed	Serious Invaders
Plants	72	68	36
Animals	70	61	33

As floodplains merge into Delta riparian habitat, many of these plants are still present, along with additional pests like perennial pepperweed (*Lepidium latifolium*) and Russian thistle (*Salsola soda*). Also in the Delta, and in Bay habitats downstream,are whole hosts of invasive animals and fully aquatic plants. Oftentimes these non-indigenous species interact to promote each other's establishment, such as exotic plants altering soil to favor other exotic plants, or providing habitat for introduced predators and yielding a more insidious problem than would have been presented by a single species alone.

Given the current interest in restoration of many areas toward their former natural condition, and in creation of new habitat as mitigation for environmental losses elsewhere, the role of non-indigenous species in these sites becomes critical. However, many invasive species are particularly well-adapted to establishment in areas that have been mechanically disturbed, as would be the case following habitat restoration. For example, smooth cordgrass (*Spartina alterniflora*) from the Atlantic coast has invaded numerous sites in the south Bay where tidal mudflat restoration or creation has been undertaken, such that it could become advisable to clear the slate and start over.

Likewise, in brackish/freshwater marsh projects, such as Warm Springs Marsh and Sonoma Baylands, perennial pepperweed is invading newly-cleared substrates from levees and spoils sites nearby. Stone Lakes Wildlife Refuge is restored agricultural land, but experiences severe water hyacinth infestation requiring control each year. In smaller streams nearly every riparian restoration project we've observed in the Bay Area (e.g. Strawberry Creek, Wildcat Creek, Sausal Creek, Presidio streams, and many others) is inundated by the many invasive plants mentioned earlier, by encroachment from adjacent landscapes or waterflow; or by inadequate removal of invasive plants during the restoration work itself.

REHAB ADVICE

- Be prepared. Restoration sites are particularly susceptible to invasions. Take careful account of the potential for invasion as watershed-wide projects are planned and undertaken.
- Remember that the following may promote invasions: hydrological changes/flow regulation; channel and soil disturbance;loss of native riparian habitat;and nutrient inputs.
- Coordinate restoration plans with surrounding land uses and possible invasive species impacts.
- Put some effort into making sure you get the vegetation you want at your restoration site (build it and they will come).
- Maintain constant vigilance over restoration sites. Support monitoring programs that will provide early detection of invasive species and follow-up control,so as to avoid the greater expense of secondary restoration of these habitats at a later date (Dudley, SOE, 1999).

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PROJECT IN ACTION

Common Reed Control

Control of the common reed *(Phragmites australis)*, an aggressive invasive plant that grows in moderately to highly saline environments, is a central element in an effort by Grizzly Island's TuleRed Duck Club to restore a portion of its property disturbed by a drainage ditch and to enhance adjacent wetlands. The project aims to lessen the impact of non-native vegetation and promote the growth of native wetland plants that in turn provide habitat for endangered species, as well as the familiar ducks and geese that visit the Delta. To begin the project in 1995, biologists surveyed and examined the levees, interior lands and the bay shoreline and determined historic water levels, flows and tidal flooding, as well as associated percent cover and frequency of plant species. Management practices then undertaken include disking, mowing and applying herbicides, which reduced nonnative plants, then seeding and allowing the area to be recolonized by the marshland species ducks prefer. Subsequent site monitoring shows that aggressive management can control the common reed. However, because of the plant's invasive nature, treated areas will soon revert to dense stands of common reed without continued management (Redpath, SOE Poster, 1999).

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CHEMICAL CONTAMINATION
IMPLICATIONS FOR REHABILITATION

Sam Luoma,U.S. Geological Survey

Though chemical contamination of the San Francisco Bay-Delta has diminished since passage of the Clean Water Act in 1970,a range of biological indicators suggest contaminant stress continues. These include sediment toxicity, tissue residues of contaminants, biochemical and histological indicators of stress in resident organisms, reproductive anomalies in resident organisms, simplified communities and unstable populations. Solving the remaining problems will not be simple. On-going study of contamination issues is crucial to the sustainable rehabilitation of the Bay-Delta ecosystem.

The status of contamination is influenced by several factors:modern inputs from human activities; historic human activities like mining;and the physical,chemical and biological characteristics of the system. Other important influences include changes in freshwater inflows and water movement patterns, patterns of sediment deposition and erosion,the interchange of water and sediments between all segments of the Bay-Delta,phytoplankton blooms and food web characteristics.

Recent scientific studies point to a number of contamination issues that will be important as we move into the rehabilitation phase of estuarine management in the next century:

Contaminant Exposure Links with Bay Physical Characteristics

- Studies of historic lead contamination (Ritson et al,1999) show that contaminants from single point sources can spread throughout the interconnected reaches of the Bay-Delta,probably because the Bay is a shallow and well-mixed system.
- Hotspots of polychlorinated biphenyls (PCBs) have been identified (Davis et al,SOE Poster, 1999). Despite bans on production decades ago, PCB concentrations in the Bay overall are not declining as rapidly as in many areas of the world. The ability of the Bay to spread contaminants from point sources over large areas may be one cause of continuing regional-scale PCB contamination in water, sediments and birds. Studies of PCB redistribution are badly needed and new approaches to remediation of highly dynamic Bay sediments may be necessary.

NEW SCIENCE

Metal Dynamics in Intertidal Wetlands

Multidisciplinary studies of selenium and heavy metal cycling in intertidal marshes in the Carquinez Strait have yielded estimates of the relative importance of processes by which trace elements are imported into the system. Sampling, fractionation, and analysis of sediments from the surface depth of 20 cm, both in marsh and mudflat environments, show selenium to be predominantly (>90%) chemically reduced, i.e. relatively immobile and insoluble in elemental and organic forms. Similarly, after deposition, particle-bound selenium does not become further reduced in shallow sediments.

Concentrations of all trace elements were found to increase from mudflat to marsh, apparently due to the differences in the size of the particles which settle out in each of these environments. Selenium concentrations ranged from around 0.5 parts per million (ppm) in mudflat sediments to around 1 ppm in marsh plain sediments. Significantly higher selenium and metal concentrations were associated with the finer fractions. The similar spatial distribution of selenium and trace metal concentrations in the shallow sediments supports the idea of suspended particulate matter deposition as the primary flux of selenium and trace metals to the intertidal marsh.

In-situ measurements of sediment deposition have generated estimates of sediment-associated trace element depositional rates. These results show a seasonal pattern of trace element concentration, inversely related to the flow of water in the Carquinez Strait, with concentrations lowest in the winter and highest in the summer and fall. Patterns of trace element concentrations on sediment traps agree semi-quantitatively with element distribution in the shallow marsh sediments. The results of these and related studies suggest that monitoring selenium concentrations on suspended particulate matter at the sediment-water interface may provide the data most representative of conditions to which benthic organisms are exposed (Zawislanski et al, SOE Poster, 1999).

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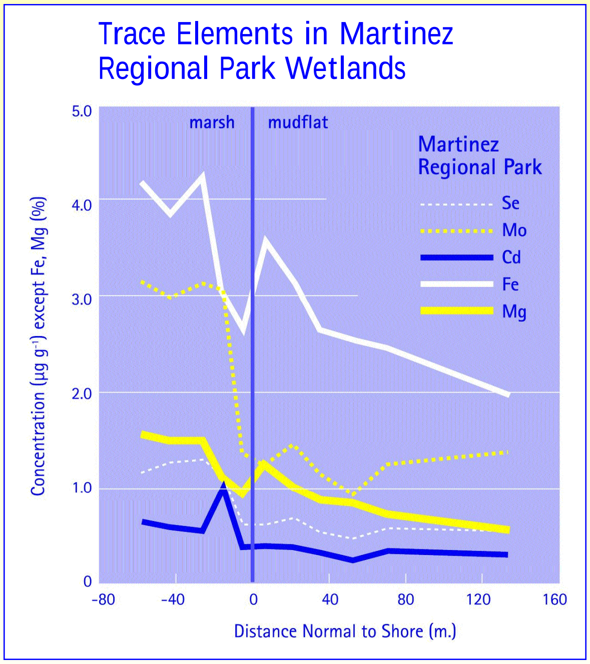


Trace element concentrations in the top 20 cm of intertidal sediment. Concentrations of all elements, including selenium, increase inland, from the mudflat to the marsh.

- The Bay's food web is contaminated with methyl mercury (SFBRWQCB, 1995). Advisories exist prohibiting human consumption of some larger, longer-lived fish,a typical sign of mercury contamination. Recent research shows that hydraulic mining debris is an important source of mercury in bay sediments (Hornberger et al, 1999). Most of the debris was buried beneath sediments that were deposited between 1890 and 1950. However, these deposits have increasingly been uncovered since the 1950s, probably as a result of the effects of dam construction (dams trap sediments higher up in the watershed (Jaffe et al,SOE Poster, 1999; Bouse et al, SOE Poster, 1999). Hydraulic mining debris deposits may be a major source of contamination to the food web.

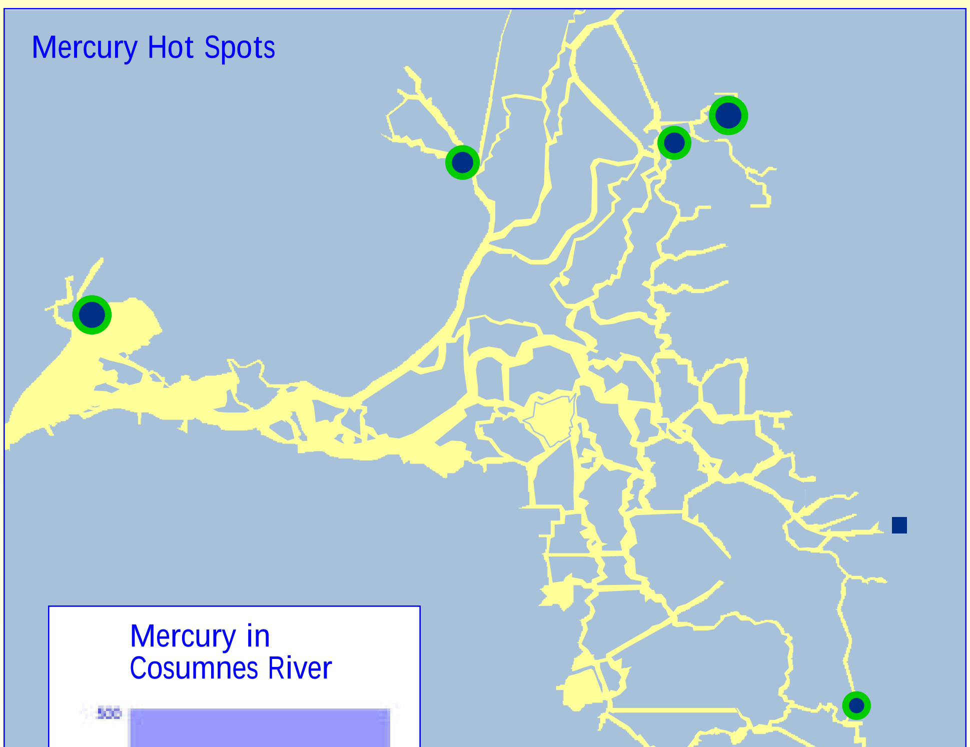
NEW SCIENCE

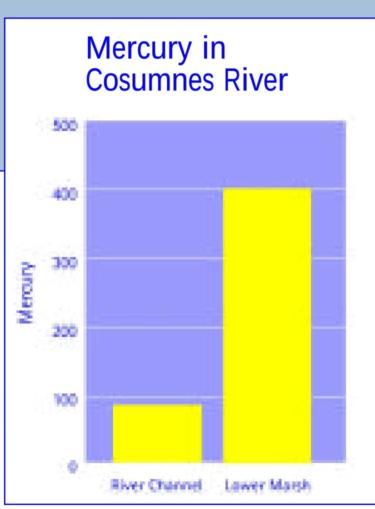
Methyl Mercury Consequences of Bay-Delta Restoration

Preliminary results of an ongoing three year study examining which key parameters most strongly affect mercury methylation in the Delta suggest that wetland restoration projects may vary significantly in localized mercury bioaccumulation, as a function of their location within the Bay-Delta.

It has been hypothesized that the restoration of former wetlands (previously diked for agricultural production) by re-flooding, together with the addition of thousands of acres of new tidal wetlands to the overall system, may result in a net increase in the production of methyl mercury — the most-dangerous and bioavailable form of this metal — in the Bay and Delta. Though the habitat benefits of such restoration work are clear, a significant net increase in fish mercury levels and associated human health and wildlife exposures would be detrimental.

This CALFED-funded study quantifies relative mercury bioaccumulation by key, site specific indicator organisms at numerous Delta sites spanning a range of physical, chemical and biological gradients that may be important to mercury methylation.





These gradients include salinity, sediment mercury load and speciation, age of tract since re-flooding, Coast Range mercury mining inputs versus Sierra Nevada refined quicksilver inputs, potential ameliorative effects of selenium from San Joaquin (Kesterson) inputs versus Sacramento River inputs, etc. Monitoring is focused on organisms with high site fidelity — crayfish, small and juvenile fish, clams, etc. — as opposed to highly mobile adult fish.

Additionally, the relative potential of sediments from various tracts for mercury methylation has been quantified in laboratory experiments.

Findings from Fall 1998 **&** Spring/Summer 1999 from 29 diverse sites indicate similar levels of mercury bioaccumulation across much of the central Delta, with significantly elevated levels linked primarily to proximity to certain regions. Apparent source-related regions include the Cosumnes River (un-dammed Sierra Nevada quicksilver inputs), portions of the North Delta Wetlands (Coast Range mercury mine inputs), and possibly the San Joaquin River above Stockton (additional Sierra Nevada inputs). An apparent hot spot in the Suisun Slough region may be linked to the salinity gradient/entrapment zone. In related laboratory experiments, researchers have demonstrated a dramatic enhancement of mercury methylation potential in organic-rich Bay-Delta wetland habitats, as compared to sand flats and typical channels.

All wetland conversion will likely enhance localized mercury methylation to some degree. But these findings suggest that future wetland restoration strategies least likely to increase net mercury methylation rates and associated biological uptake may include strategic placement of restoration sites away from known elevated mercury source areas and otherwise high methylation regions of the system, as determined by research. The project is currently processing a large set of consistent samples collected in Fall 1999 from over 70 diverse sites. These should provide greatly enhanced resolution of Bay-Delta mercury bioaccumulation trends. In addition, ongoing laboratory experiments will further refine understanding of the regional and microhabitat factors influencing mercury methylation (Slotton et al, SOE Poster, 1999 **&** Pers. Comm., 2000).

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Changing Inputs

- If marsh restoration proceeds at locations contaminated with mercury-laden hydraulic mining debris, mercury contamination in the Bay food web could worsen.
- Selenium occurs in elevated concentrations in sturgeon and some migratory birds in the Bay (Urquhart and Regalado, 1991),and threatens reproduction in these species. The processes that caused the historic selenium problem were identified in the 1980s (Cutter 1989; Johns 1989; Luoma et al 1992). However the issues surrounding selenium contamination are changing. Proposals exist to discharge selenium from saline soils of the Western San Joaquin Valley directly into the Bay. As a result of changes in water management, San Joaquin River inflows to the Bay may be on the rise. Selenium concentrations in bivalves are presently higher than they were in the late 1980s, despite reductions in local oil refinery inputs of the element. The cause of higher bivalve contamination is not fully known.
- Sporadic large inputs of modern pesticides from rivers and streams in the Bay are linked to periods of high river inflows. Inputs were once thought to be confined to short-term pulses, but new data show increased concentrations of some pesticides can extend for months in Suisun Bay (Kuivila,SOE Poster, 1999).

Contaminant Mixtures

- Analytic methods are only available for determination of 16% of the pesticides used by California agriculture (Kuivila et al,SOE Poster, 1999). Nevertheless, 50% of the water samples collected from the San Joaquin River have seven or more pesticides that are detectable. Similarly in the Bay, the simultaneous presence of a wide variety of pesticides is an important potential problem. Toxicity of pesticide-contaminated waters is apparently widespread in rivers. But effects on resident species in the Bay and its watershed are not known,and the effects of mixtures of pesticides have not been adequately addressed.

Surprises on the Horizon

- Contamination with combustion related hydrocarbons (e.g. polyaromatic hydro-carbons — PAHs) appears to be widespread in the Bay. PAH uptake and induction of biochemical detoxification systems were related to reproductive problems in starry flounder fifteen years ago (Spies 1998). But little further study has occurred, even though areas being proposed for restoration and dredging could contain significant PAH deposits.
- Historically silver and copper contamination at a hotspot in the South Bay caused reproductive failure in local resident bivalves. As a result of

PROJECT IN ACTION

Sediment Remediation at United Heckathorn

The United Heckathorn site, located in San Francisco Bay's Richmond Harbor, was used to formulate pesticides between 1947 and 1966. Soils at the site and sediment in Richmond harbor were contaminated with chlorinated pesticides, primarily DDT, as a result of shipping and formulating activities. DDT is a persistent and bioaccumulative toxic substance which was banned by the U.S. Environmental Protection Agency (EPA) in 1972. EPA listed United Heckathorn as a Federal Superfund site after California State Mussel Watch monitoring data showed that the mussels in Richmond Harbor had the highest DDT concentrations in the state. EPA responses began in 1990-1993, with the removal of roughly 3,000 tons of pesticide residues and contaminated shoreline soils. Studies of contaminated harbor sediments in 1994 found DDT as high as 630 parts per million (PPM) dry weight at the head of the Lauritzen Channel. Cleanup occurred in 1996-1997, and involved dredging of 112,660 tons of sediment containing approximately three tons of DDT. The sediment was then dewatered on site, and shipped by rail to permitted landfills. In April 1997, the dredged channel was capped with 0.5-1.5 feet of clean sand.

Long-term monitoring to assess the effectiveness of clean up showed that chlorinated pesticide concentrations in resident mussel tissue were reduced by 61-70% from pre-remediation levels by the second year. These reductions occurred not only at the site, but also throughout Richmond Harbor. Similar reductions occurred in dieldrin and PCB levels. However total DDT in the Lauritzen Channel water and in the semi-enclosed adjacent waterways still exceeded the remediation goal of 0.59 nanograms per liter (Lincoff et al, SOE Poster, 1999). These and results of other monitoring (Anderson, SOE Poster, 1999) suggest that dredging of the channel sediments did not sufficiently reduce risk of exposure of chemicals of concern to resident benthic biota. Lauritzen Channel sediments continue to be contaminated by concentrations of DDT, dieldrin, and in some cases PAHs, that are sufficient to account for amphipod mortality in laboratory experiments. Such results demonstrate the importance of chemical and biological monitoring at San Francisco Estuary sites proposed for sediment remediation, and suggest that multiple indicators that consider both water and sediment exposure pathways be used in future post-remediation monitoring studies.

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Total DDT in Resident Mussels (ppb, wet wt.)

STATION	1991-92 (pre-dredging)	1998 (1st year)	1999 (2nd year)
Lauritzen Channel (center)	2900	4504	606
Lauritzen Channel (mouth)	-	1222	176
Santa Fe Channel	350	256	75.6
Richmond Inner Harbor	40	127	29.7

improvements in advanced waste treatment and source control, contamination has receded, and reproduction in the clams has returned to successful levels (Hornberger et al,SOE Poster, 1999b). Evidence from the North Bay also suggests that cadmium and silver may chemically interfere with reproduction in resident fauna (Brown,SOE Poster, 1999). Effects of metals on reproduction of animals is indicated by both studies, but has not been adequately researched.

- Primary sources of copper have changed since 1990. Questions about ecological effects of copper and nickel on phytoplankton in the South Bay remain unanswered. New South Bay issues, such as bridge construction and airport runway modifications, could influence future effects of silver, copper, mercury, cadmium and PAHs that may be buried in bay sediments.

REHAB ADVICE

- Obtain sediment cores to test for chemical contamination from areas proposed for restoration,dredging or any increase in hydraulic residence times. Hydraulic mining debris, mercury, selenium,PCBs, metals and PAHs are of concern. Where contaminants are present, study remediation methods and undertake remediation when possible before restoration begins. Work to better understand if and where disturbance of sediments, or other activities accompanying habitat enhancements, mobilize contaminants in bioavailable forms. Precedent exists for increasing contamination problems by flooding lands (i.e. for restoration) in the absence of contaminant remediation measures.
- Consider improvements to San Joaquin River water quality as part of any proposal to increase its inflows into the Bay. Some water management proposals aimed at helping improve Delta farming, environmental and habitat conditions may result in greater quantities of poor quality San Joaquin River water entering the Bay than under current conditions. Selenium and pesticide contamination are of particular concern.
- Remember that restoration of some species may be inhibited unless pesticide inflows are better controlled, judging from the widespread indications of pesticide toxicity in the watershed. Researchers and environmental managers should work to better understand the effects of mixtures of pesticides, and the combination of pesticide exposure with other Bay-Delta stresses, in order to identify appropriate control procedures and justify their expense.
- Identify and clean-up hotspots of contamination,and identify areas where hotspots in sediments may be uncovered. Once on the surface, contaminated sediments may be distributed throughout the Bay (Luoma,SOE, 1999).

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PROJECT IN ACTION

Guidelines for Ecosystem-Friendly Cities & Farms

The way cities and farms grow, operate and use water has an enormous impact on the health of the Bay-Delta ecosystem, and on opportunities for ecosystem restoration. Though there was not enough room in this report to cover the myriad actions that urban residents, land use planners and farmers may take to promote restoration, the following resources provide excellent action lists.

- *Improving Our Bay-Delta Estuary Through Local Plans and Programs: A Guidebook for City and County Governments*, ABAG (Including a checklist of policy options for protecting water quality, wetlands and wildlife).

➤ MORE INFO? (510)622-2465

- *Blueprint for a Sustainable Bay Area, Urban Ecology* (Ideas for homes, neighborhoods, cities and the region, with case studies.)

➤ MORE INFO? (510)251-6330

- *Agricultural Solutions: Improving Water Quality in California Through Water Conservation and Pesticide Reduction*, Natural Resources Defense Council

➤ MORE INFO? (415)777-0220

- *Farming for Wildlife, Voluntary Practices for Attracting Wildlife to Your Farm*, California Department of Fish & Game, (Specifics on beneficial farming practices aimed at the farming community.)

➤ MORE INFO? (916)653-1768

- *Local Wetland Protection Handbook*, Save the Bay (Ways for local governments, agencies, stakeholder organizations and individual citizens to protect and restore wetlands).

➤ MORE INFO? (510)452-9261